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OPTIMIZING PROCESS PARAMETERS OF NANO SIC REINFORCED AA6061 COLD EXTRUSION USING RESPONSE SURFACE METHOD

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ABSTRACT

The paper focus on preparation of AA 6061 composites with nanoSiC dispersed at varying weight fractions. AA 6061 billets are extruded by varying extrusion ratio, die included angle, ram speed and %SiC, considering Force required for extrusion, hardness, tensile strength and surface roughness as output responses. Design of experiments based Response Surface Method (RSM) is adopted and 31 experiments are performed as per Central Composite Design (CCD). Empirical mathematical equations are developed for the output responses and Analysis of Variance (ANOVA) is carried out at 95% confidence level. Main effect plots are drawn to understand the variation of input parameters with respect to output responses. Contour plots are drawn to find the most influenced parameter. Surface plots are drawn to identify the optimum input parameters.

***KEYWORDS**: Extrusion, AA 6061, Nano Sic, Response Surface Method, Contour Plots & Surface Plots*

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Original Article

INTRODUCTION

Extrusion is one of the major metal forming processes used in transforming the size and shape of the materials from the casts structure of an ingot to a useful product. Extrusion is a flexible manufacturing process, as a single extrusion press may be used for multiple materials and can produce infinite number of shapes by simply changing the die and the tooling associated with it. Aluminium is the most widely used material for extrusion process because of its considerable strength and also easily deformable properties. At present, the extrusion process parameters are selected on the basis of experience and the trial runs. Extrusion is a very complicated process which requires proper process parameters to be used to get optimum settings to produce a quality product. Therefore, most of the researchers are inclined towards the selection of optimum parameters which gives the best quality product.

Cunsheng Zhang et al. [1] opted for Taguchi's design of experiments and s/n ratio analysis to obtain uniform flow velocity distribution and to minimize the extrusion force in direct extrusion of Al 6063 aluminium alloy by using billet diameter, container temperature, billet preheated temperature, ram speed and die temperature as process parameters. Four levels of each parameter were used for the investigation of process. The minimum velocity distribution was obtained at higher ram speed and tooling temperatures, whereas minimum extrusion force was obtained with lower ram speed and higher tooling temperature. Billet diameter had the maximum effect on velocity distribution followed by ram speed and die temperature, whereas ram speed was the most influencing parameter for extrusion force followed by billet diameter and die temperature. Billet temperature and container

temperature had the least effect on the response parameters. Abdul Kareem et. al.[2] investigated effect of initial billet temperature, ram speed, extrusion ratio, profile average thickness and number of die cavities on the profile exit temperature using statistical design of experiments for Al 6063 aluminium alloy. A five actor and two levels design for each factor is considered for the experimentation purpose. Extrusion ratio has the strongest effect on the profile exit temperature followed by ram speed, initial billet temperature, profile average thickness and then the number of cavities. F. Fereshteh Sanieeet. al. [3] used Taguchi method to investigate the effects of three die profiles and three extrusion ratios on the extrusion force. L_9 orthogonal array was selected for analysing the experimental results.

The objective of the present work is to develop empirical mathematical models for extrusion force required, hardness, tensile strength and surface finish. Analyse the effect of input parameters on output responses.

EXPERIMENTATION

The experimental setup for the fabrication of MMNCs is shown in Figure-1. The equipment includes melting furnace, ultrasonic transducer probe (1 kW, 20 KHz), temperature controller and inert gas protection nozzles. An electrical resistance heating unit is used for melting of AA6061 in a graphite crucible of a 1 kg capacity. Nanosized SiC particles are fed into melt during the ultrasonic processing. The aluminium melt is protected from oxidation by creating an inert atmosphere with argon gas. Argon gas cylinder (max. pressure=220bar) with a pressure regulator and pressure gauge is used to supply shielding gas to the molten metal A mechanical stirrer is also used in the process to stir the melt before sonication.

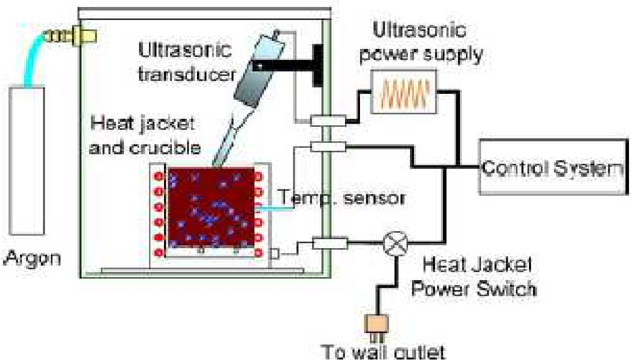

Figure 1: Ultrasonic Fabrication Equipment Setup

Round bars of dimensions of 30 mm diameter and 200 mm length are produced by using the permanent mould made of mild steel. Specimens are cut from the as cast bars to a size of 37.5mm and turned to 25 mm.

A graphite crucible is used for preheating the SiC particles and a skimmer coated with graphite is used to remove slag after complete melting. The base metal AA6061 is taken in a graphite crucible. The melting temperature is maintained at approximately 100°C above the alloy melting point i.e., 650°C. This enables the flowability of molten metal into the mould [4]. SiC nano particles are added to the molten metal at 0.1 wt.% gradually into the molten metal. As nanoparticles being lighter in weight try to float on the surface of the molten metal. Therefore before sonication process, stirring is done using mechanical stirrer at a speed of 1500 rpm for 6 minutes. Then an ultrasonic probe with 1 kW output is used to generate adequate sonication power inside the crucible. The probe is made of niobium (Nb), which can withstand high processing temperatures and bubble burst pressures. Sonication time is fixed as 6 minutes for 0.1 wt.% and it is increased by 6 minutes for every 0.1wt.% increment. After ultrasonic processing, the Aluminium melt is cast into a preheated steel

permanent mould, a thin layer of graphite powder is applied to the inner walls of the mould for easy removal of the solidified casting from the mould. The steel mould was preheated to 350°C with a gas torch. AA6061 nanocomposites with various weight percentages (0.1, 0.2, 0.3, 0.4, 0.5 wt.%) of nano sized SiC are fabricated. The above procedure is repeated for fabrication of all the composites.

The billets considered for the experimentation are of initial diameter 25 and height 37.5 mm respectively In order to eliminate the problem of buckling of the billet, the height to diameter ratio is kept at 1.5for all the cases. The billets were subjected to annealing treatment to eliminate any residual stresses present prior to extrusion. This consists of heating the billets to 300^{o}C in a muffle furnace soaking at this temperature for 15 minutes followed by gradually cooling in air to room temperature. The fabricated billets are presented in Figure-2.

These % wt. wise nano SiC reinforced Al 6061 billets are extruded through dies of various combinations of included angle and extrusion ratios at various ram speeds. For all these combinations extrusion force is measured using Electronic Compression testing machine, Hardness (Rockwell) is measured with Brinell hardness tester, Surface roughness with Talysurf and Ultimate tensile strength (UTS) using electronic universal testing machine.

Figure 2: Nano SiC Reinforced Al 6061 Billets (0.1% To 0.5% Sic Weight Wise)

An extrusion tool designed for the analysis consists of mainly three parts the punch, container and die. The dies are designed in accordance with K. Geethalakshmi [5]. Dies are made with included angles of 12^{o}, 14^{o}, 16^{o}, 18^{o}, 20^{o}and each die having the exit diameters 18mm, 19mm, 20mm, 21mm and 22mm. The land length is kept constant as 4mm. The die is made of high carbon high chromium steel. The die is heat treated to increase hardness and finished. Figure-3 indicates the dies used for extrusion. Figure 3 represents some of the critical dimensions of drawing die.

Figure 3: Drawing Dies

DESIGN OF EXPERIMENTS

Based on trial experiments, the levels of each individual input variable are decided. The level of each variable is decided by varying its value from minimum to maximum keeping other variables constant and based on visual inspection ranges of each variable are fixed [6]. The following observations are made while conducting trial experiments.

The upper limit of a factor was coded as +2 and the lower limit as -2, the coded values being calculated from Equation-1.

$$X_i = 2[2X - (X_{max} + X_{min})] / (X_{max} - X_{min}) \quad (1)$$

where $X_i$is the required coded value of a variable X, varying from X_{min} to X_{max}.

For four factors and five levels, as per RSM, CCD design 31 experiments need to be performed. Parameters and their levels are presented in Table-1 and experimental values are presented in Table-2.

Table 1: Process Parameters and their Limits

Factors	Levels				
	-2	-1	0	+1	+2
Extrusion ratio	1.04	1.14	1.25	1.39	1.56
Included angle	12	14	16	18	20
Ram speed (mm/min)	1	1.5	2	2.5	3
% SiC Nanoparticles	0	0.1	0.2	0.3	0.4

Table 2: Experimental Results

Exp. No	Input				Output (Experimental)			
	Extrusion Ratio	DieIncluded Angle (Deg.)	Ram Speed (mm/min)	%SiC	Extrusion Force (KN)	Hardness (Rockwell)	UTS (MPa)	Surface Roughness (Microns)
1	1.14	14	1.5	0.1	184	112	171	0.249
2	1.39	14	1.5	0.1	189	114	176	0.259
3	1.14	18	1.5	0.1	188	113	166	0.247
4	1.39	18	1.5	0.1	187	115	174	0.252
5	1.14	14	2.5	0.1	189	114	173	0.242
6	1.39	14	2.5	0.1	189	116	174	0.252
7	1.14	18	2.5	0.1	185	115	163	0.238
8	1.39	18	2.5	0.1	189	116	174	0.243
9	1.14	14	1.5	0.3	188	114	172	0.247
10	1.39	14	1.5	0.3	190	115	174	0.256
11	1.14	18	1.5	0.3	192	116	173	0.247
12	1.39	18	1.5	0.3	194	117	174	0.251
13	1.14	14	2.5	0.3	192	115	184	0.25
14	1.39	14	2.5	0.3	194	116	186	0.258
15	1.14	18	2.5	0.3	195	117	181	0.249
16	1.39	18	2.5	0.3	196	118	186	0.252
17	1.04	16	2	0.2	181	114	172	0.24
18	1.56	16	2	0.2	198	116	180	0.253
19	1.25	12	2	0.2	186	114	182	0.256
20	1.25	20	2	0.2	194	117	173	0.247
21	1.25	16	1	0.2	186	114	172	0.255
22	1.25	16	3	0.2	193	116	180	0.247
23	1.25	16	2	0	179	111	165	0.244
24	1.25	16	2	0.4	198	117	186	0.255
25	1.25	16	2	0.2	186	116	176	0.25

Exp. No	Input				Output (Experimental)			
	Extrusion Ratio	DieIncluded Angle (Deg.)	Ram Speed (mm/min)	%SiC	Extrusion Force (KN)	Hardness (Rockwell)	UTS (MPa)	Surface Roughness (Microns)
26	1.25	16	2	0.2	190	116	175	0.253
27	1.25	16	2	0.2	192	116	172	0.253
28	1.25	16	2	0.2	190	115	175	0.246
29	1.25	16	2	0.2	191	115	176	0.25
30	1.25	16	2	0.2	188	115	175	0.253
31	1.25	16	2	0.2	190	115	173	0.251

Development of Mathematical Models

In RSM design, mathematical models are developed using polynomial equations. The type of polynomial equation depends on the problem.

In most RSM problems [7,8], the type of the relationship between the response (Y) and the independent variables is unknown. Thus the first step in RSM is to find a suitable approximation for the true functional relationship between the response and the set of independent variables.

Usually, a low order polynomial is some region of the independent variables is employed to develop a relation between the response and the independent variables. If the response is well modeled by a linear function of the independent variables then the approximating function in the first order model is

$$Y = b_o + \sum b_i x_i + \in \quad (2)$$

where b_o, b_i are the coefficients of the polynomial and $\in$ represents noise or error.

If interaction terms are added to main effects or first order model, then the model is capable of representing some curvature in the response function, such as

$$Y = b_o + \sum b_i x_i + \sum\sum b_{ij} x_i x_j + \in \quad (3)$$

A curve results from Equation -3 by twisting of the plane induced by the interaction term $b_{ij}x_ix_j$.

There are going to be situations where the curvature in the response function is not adequately modeled by Equation-3. In such cases, a logical model to consider is

$$Y = b_o + \sum b_i x_i + \sum b_{ii} x_i^2 + \sum\sum b_{ij} x_i x_j + \in \quad (4)$$

where b_{ii}represent pure second order or quadratic effects. Equation-4 represents a second order response surface model.

Using MINITAB Ver.14, a statistical software, the significant coefficients are determined and final models are developed incorporating these coefficients to estimate drawing die force, hardness, UTS and surface finish.

$$\text{Extrusion Force} = 160.532 + 6.959\,X_1 - 0.052X_2 + 9.127X_3 - 44.566X_4$$

$$\text{Hardness} = 76.8204 + 35.6767\,X_1 - 0.0133X_2 + 5.0914X_3 + 26.9549X_4$$
$$-31.1745X_4^2 + 1.5625X_2X_3$$

$$\text{UTS} = 270.315 - 27.848\,X_1 - 9.960X_2 - 6.635X_3 - 51.151X_4 + 3.901X_1X_2$$

$-79.618X_1X_4+58.750X_3X_4$

Surface Roughness$=0.011422 + 0.3303\ X_1 +0.0044X_2 - 0.0049X_3 - 0.0719X_4$

$-0.0049X_1X_2\ -0.00037X_2X_3+0.050X_3X_4$

where X1, X2, X3, X4 for the coded values of Extrusion ratio, Included angle, ram speed, %SiC

Checking the Adequacy of the Developed Models

The adequacy of the developed models is tested using the ANOVA. As per this technique, if the calculated value of the F_{ratio} of the developed model is less than the standard F_{ratio} (F-table value 7.87) value at a desired level of confidence of 99%, then the model is said to be adequate within the confidence limit. ANOVA test results are presented in Table 3 for all the models of extrusion. From Table 3, it is understood that the developed mathematical models are found to be adequate at 95% confidence level. Coefficient of determination 'R^2' is used to find how close the predicted and experimental values lie. The value of 'R^2' for the above developed models is found to be about 0.92, which indicates a good correlation to exist between the experimental values and the predicted values.

Table 3: ANOVA Test Results

Analysis of Variance for Extrusion Force (KN)						
Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**
Regression	14	462.693	462.693	33.0495	4.05	0.005
Linear	4	433.400	3.495	0.8737	0.11	0.978
Square	4	3.700	3.700	0.9250	0.11	0.976
Interaction	6	25.592	25.592	4.2653	0.52	0.783
Residual Error	16	130.727	130.727	8.1704		
Lack-of-Fit	10	107.013	107.013	10.7013	2.71	0.188
Pure Error	6	23.714	23.714	3.9542		
Total	**30**	**593.419**				
Analysis of Variance for Hardness (Rockwell)						
Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**
Regression	14	63.057	63.057	4.5041	14.03	0.000
Linear	4	56.569	2.055	0.5137	1.60	0.223
Square	4	3.449	3.449	0.8623	2.69	0.069
Interaction	6	3.039	3.039	0.5065	1.58	0.217
Residual Error	16	5.136	5.136	0.3210		
Lack-of-Fit	10	3.422	3.422	0.3422	1.20	0.430
Pure Error	6	1.714	1.714	0.2857		
Total	**30**	**68.194**				
Analysis of Variance for UTS (MPa)						
Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**
Regression	14	920.960	920.960	65.783	18.47	0.000
Linear	4	725.181	26.338	6.585	1.85	0.169
Square	4	8.673	8.673	2.168	0.61	0.662
Interaction	6	187.106	187.106	31.184	8.76	0.000
Residual Error	16	56.975	56.975	3.561		
Lack-of-Fit	10	43.261	43.261	4.326	1.89	0.225
Pure Error	6	13.714	13.714	2.286		
Total	**30**	**977.935**				
Analysis of Variance for Surface Roughness (Microns)						
Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**
Regression	14	0.000724	0.000724	0.000052	17.22	0.000
Linear	4	0.000525	0.000114	0.000028	9.46	0.000
Square	4	0.000063	0.000063	0.000016	5.21	0.007

Table 3: Contd.,

Interaction	6	0.000136	0.000136	0.000023	7.55	0.001
Residual Error	16	0.000048	0.000048	0.000003		
Lack-of-Fit	10	0.000009	0.000009	0.000001	0.14	0.996
Pure Error	6	0.000039	0.000039	0.000006		
Total	**30**	**0.000772**				

where SS = Sum of Squares, MS = Mean Squares, DF = Degree of Freedom, F = Fisher's ratio, P = probability ratio.

Main Effect Plot of Output Responses

Main plots are drawn for each output response, it is understood that

- Force required for extrusion increasess with the increase in extrusion ratio, die included angle, ram speed and %SiC.
- Workpiece hardness increase with increase in extrusion ratio, die included angle, ram speed and %SiC.
- Tensile strength increases with extrusion ratio, ram speed and %SiC, where as it increases with increase in included angle
- Surface roughness value decreases with die angle and ram speed, where as it increases with extrusion ratio and %SiC.

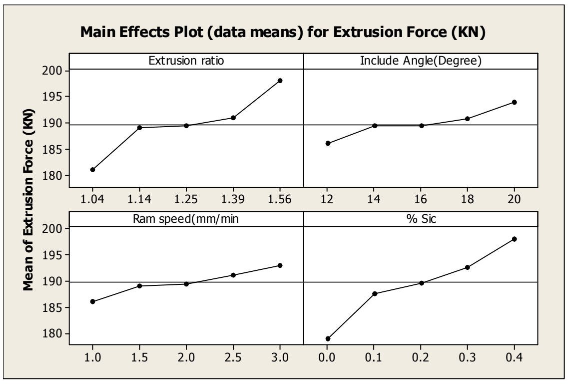

Figure 4: Main Effect Plot for Force Required

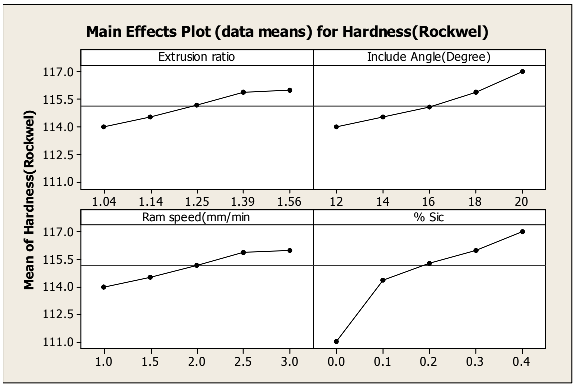

Figure 5: Main Effect Plot for Hardness

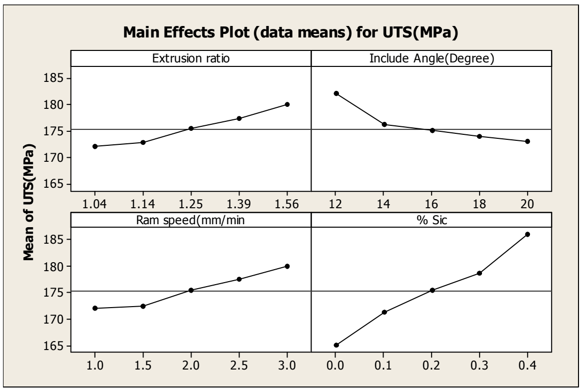

Figure 6: Main Effect Plot for UTS

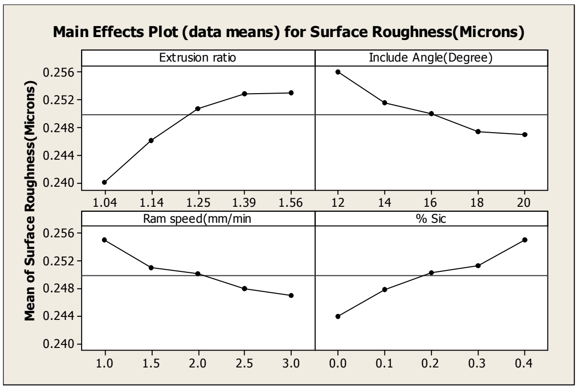

Figure 7: Main Effect Plot for Surface Finish

Contour Plots for Extrusion Parameters

Contour Plots for Force Required For Extrusion

Contour plots are drawn to identify the most influencing input parameter on output response. If the contour lines are circular in shape, it represents both the parameters has each influence. If the contour lines are elliptical in shape, the most influencing parameter is one where the contour lines are focusing. Figures 8a to 8c represents the contour plots for force required for extrusion.

From Figure 8a, it is understood that extrusion ratio is dominating die included angle.

From Figure 8b, it is understood that extrusion ratio is dominating ram speed.

From Figure 8c, it is understood that extrusion ratio is dominating %SiC.

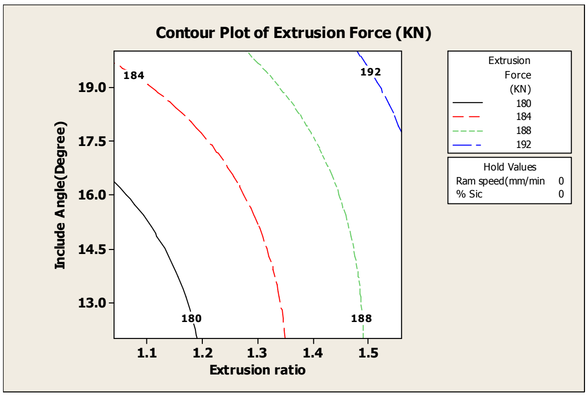

Figure 8a: Contour Plot for Force Required (Extrusion Ratio Vs Included Angle)

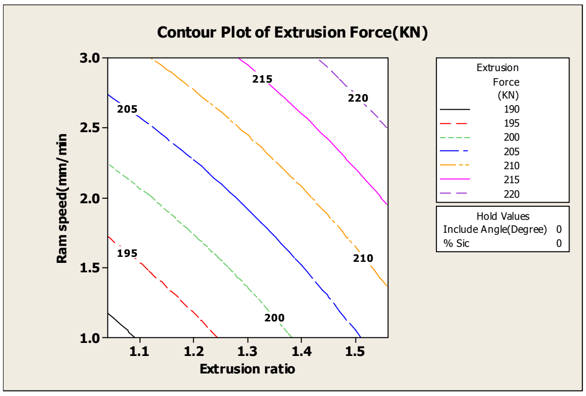

Figure 8b: Contour Plot for Force Required (Extrusion Ratio Vs Ram Speed)

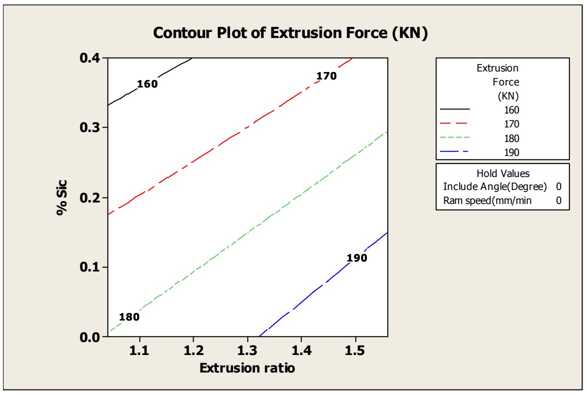

Figure 8c: Contour Plot for Force Required (Extrusion Ratio Vs %SiC)

Contour Plot for Hardness

Figures 9a to 9c represents the contour plots for hardness.

From Figure 9a, it is understood that extrusion ratio is dominating die included angle.

From Figure 9b, it is understood that extrusion ratio is dominating ram speed.

From Figure 9c, it is understood that %SiC is dominating extrusion ratio.

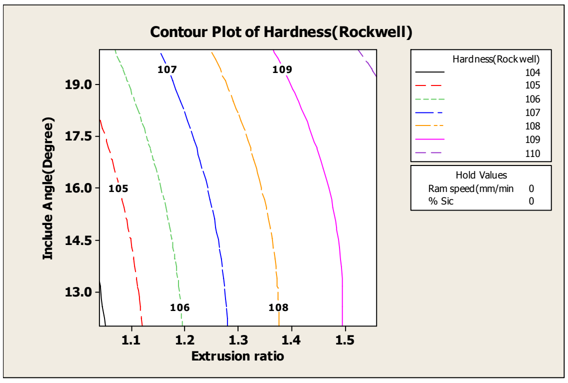

Figure 9a: Contour Plot For Hardness (Extrusion Ratio Vs Included Angle)

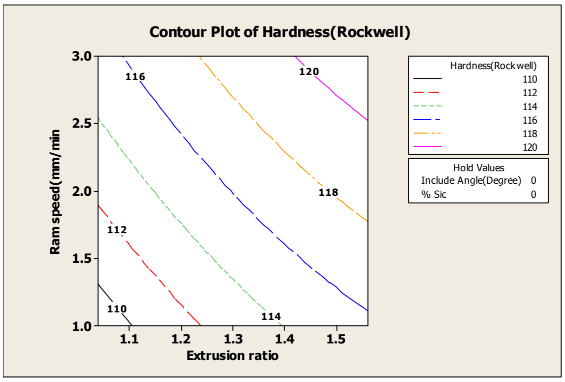

Figure 9b: Contour Plot For Hardness (Extrusion Ratio Vs Ram Speed)

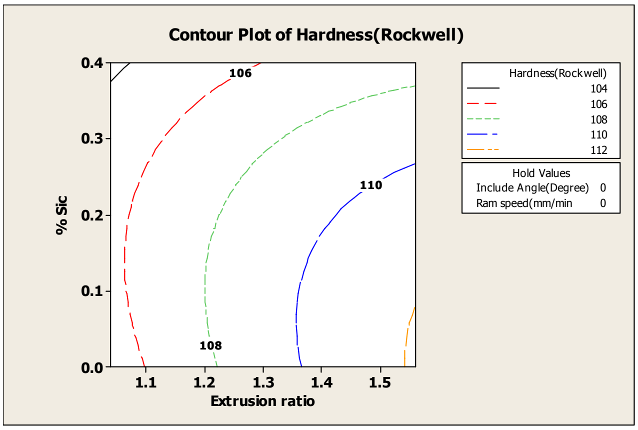

Figure 9c: Contour Plot for Hardness (Extrusion Ratio Vs %SiC)

Contour Plot for Ultimate Tensile Strength (UTS)

Figure-10a to 10c represents' the contour plots for UTS.

From Figure 10a, it is understood that extrusion ratio is dominating die included angle.

From Figure 10b, it is understood that ram speed is dominating extrusion ratio.

From Figure 10c, it is understood that extrusion ratio is dominating %SiC.

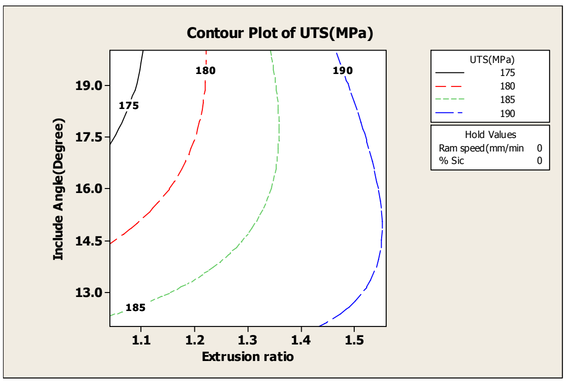

Figure 10a: Contour Plot For UTS (Extrusion Ratio Vs Included Angle)

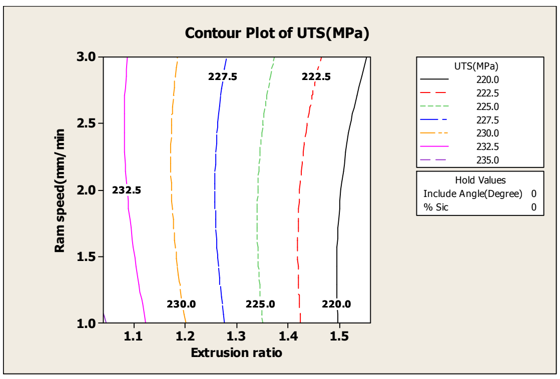

Figure 10b: Contour Plot For UTS (Extrusion Ratio Vs Ram Speed)

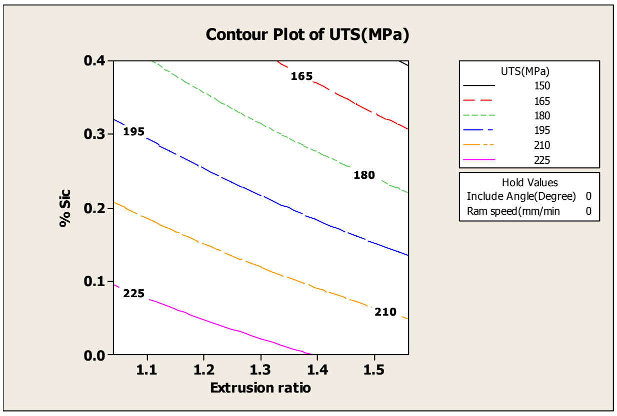

Figure 10c: Contour Plot for UTS (Extrusion Ratio Vs %SiC)

Contour Plot for Surface Finish

Figure-11a to 11c represents' the contour plots for surface finish

From Figure 11a, it is understood that die included angle is dominating die extrusion ratio.

From Figure 11b, it is understood that ram speed is dominating extrusion ratio.

From Figure 11c, it is understood that %SiC is dominating extrusion ratio.

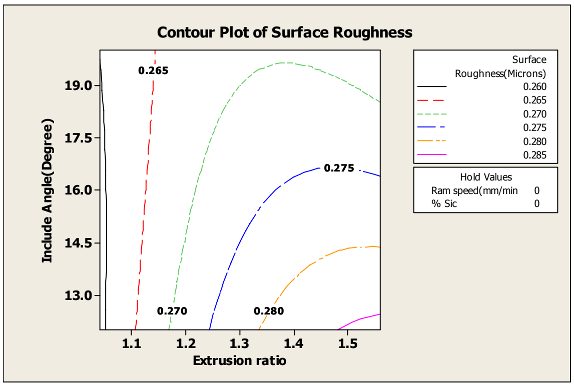

Figure 11a: Contour Plot for Surface Finish (Extrusion Ratio Vs Included Angle)

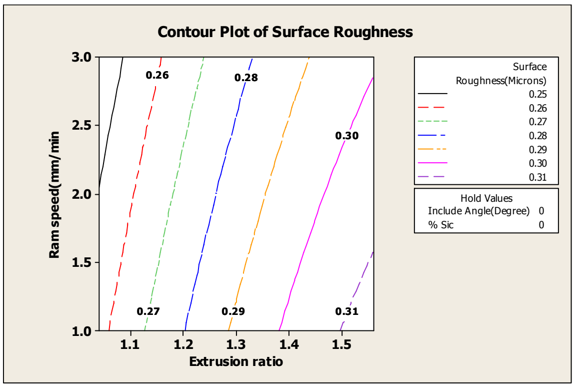

Figure 11b: Contour Plot for Surface Finish (Extrusion Ratio Vs Ram Speed)

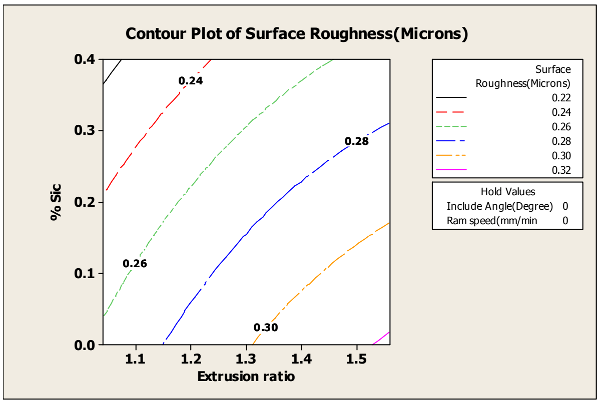

Figure 11c: Contour Plot for Surface Finish (Extrusion ratio Vs %SiC)

For extrusion force, Hardness, Tensile strength and surface finish, extrusion ratio is the most dominating input parameter, followed by ram speed and included angle.

Surface Plots for Output Responses

Surface Plot for Force Required For Extrusion

From Figure 12a, it is understood that extrusion force is minimum at extrusion ratio of 1.1 and included angle of 12°.

From Figure 12b, it is understood that extrusion force is minimum at extrusion ratio of 1.1 and ram speed of 1mm/min.

From Figure 12c, it is understood that extrusion force is minimum at extrusion ratio of 1.1 and %SiC of 0.4%.

From Figure’s 12a to 12c, it is clear that for minimum extrusion force the optimal input values, extrusion ratio of 1.1, die included angle of 12°, ram speed of 1 mm/min and %SiC of 0.4 %.

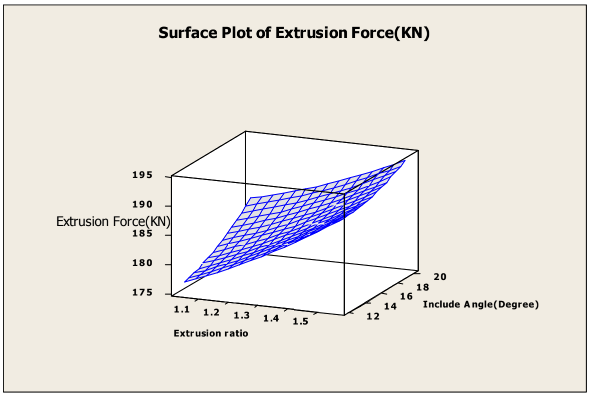

Figure 12a: Surface Plot for Forced Required (Extrusion Ratio Vs Included Angle)

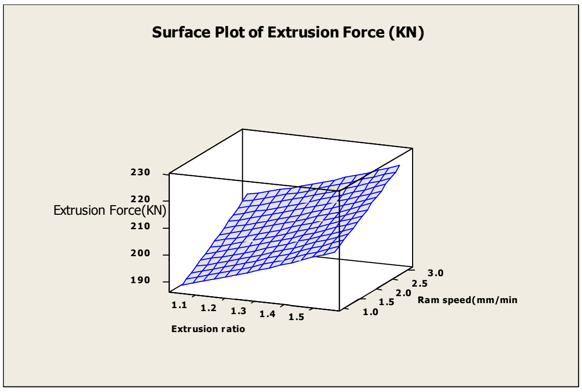

Figure 12b: Surface Plot for Forced Required (Extrusion Ratio Vs Ram Speed)

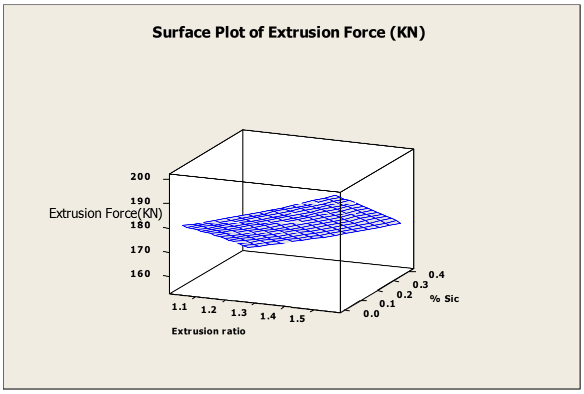

Figure 12c: Surface Plot For Forced Required (Extrusion Ratio Vs %Sic)

Contour Plots for Hardness

From Figure 13a, it is understood that hardness is maximum at extrusion ratio of 1.5 and included angle of 20°.

From Figure 13b, it is understood that hardness is maximum at extrusion ratio of 1.5 and ram speed of 3mm/min.

From Figure 13c, it is understood that hardness is maximum at extrusion ratio of 1.4 and %SiC of 0.4%.

From Figures. 13a to 13c, it is clear that for maximum hardness the optimal input values, extrusion ratio of 1.4, die included angle of 20°, ram speed of 3 mm/min and %SiC of 0.4%.

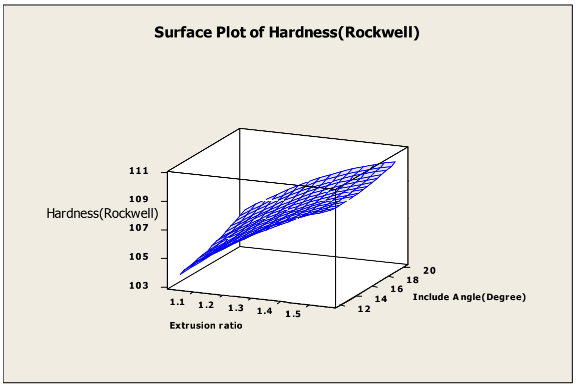

Figure 13a: Surface Plot for Hardness (Extrusion Ratio Vs Included Angle)

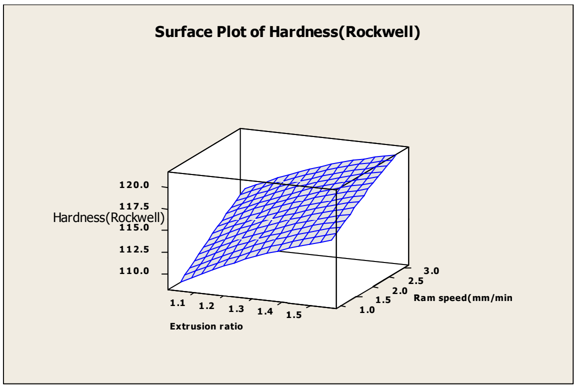

Figure 13b: Surface Plot for Hardness (Extrusion Ratio Vs Ram Speed)

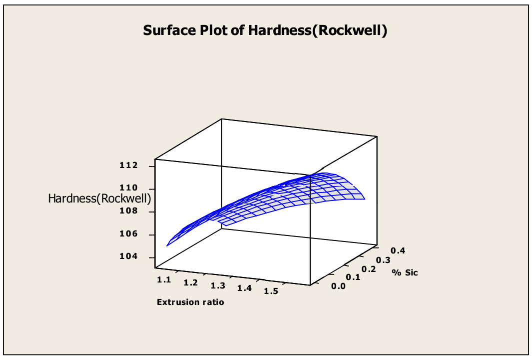

Figure 13c: Surface Plot for Hardness (Extrusion Ratio Vs %Sic)

Surface Plots for UTS

From Figure 14a, it is understood that UTS is maximum at extrusion ratio of 1.1 and included angle of 20°.

From Figure 14b, it is understood that UTS is maximum at extrusion ratio of 1.1 and ram speed of 1 mm/min.

From Figure 14c, it is understood that UTS is maximum at extrusion ratio of 1.1 and %SiC of 0%.

From Figures. 14a to 14c, it is clear that for maximum hardness the optimal input values, extrusion ratio of 1.4, die included angle of 20°, ram speed of 3 mm/min and %SiC of 0.4%.

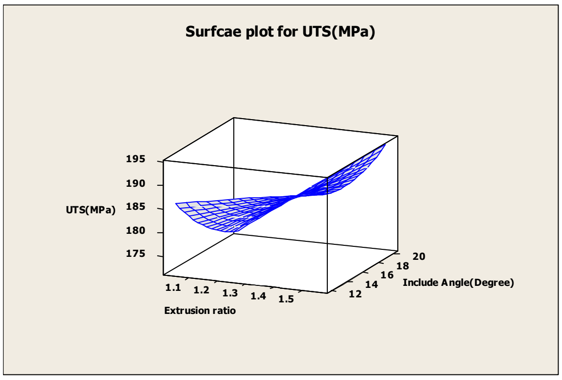

Figure 14a: Surface Plot for UTS (Extrusion Ratio Vs Included Angle)

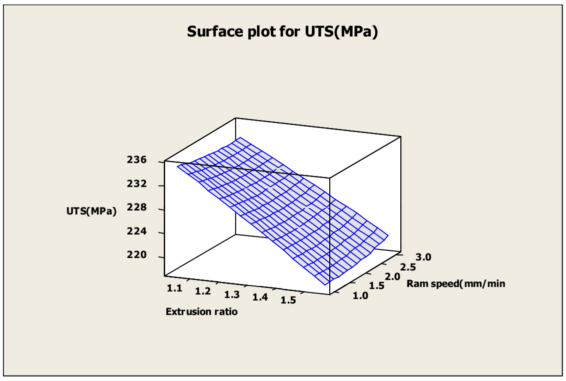

Figure 14b: Surface Plot for UTS (Extrusion Ratio Vs Ram Speed)

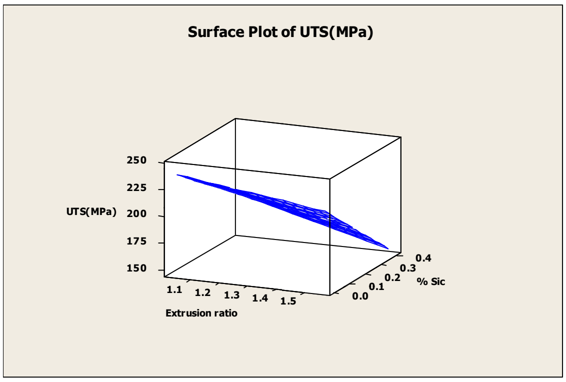

Figure 14c: Surface Plot for UTS (Extrusion Ratio Vs %Sic)

Surface Plots for Surface Finish

From Figure 15a, it is understood that surface roughness is minimum at extrusion ratio of 1.1 and included angle of 12°.

From Figure 15b, it is understood that surface roughness is minimum at extrusion ratio of 1.1 and ram speed of 3 mm/min.

From Figure 15c, it is understood that surface roughness is minimum at extrusion ratio of 1.1 and %SiC of 0.4%.

From Figures 15a to 15c, it is clear that for maximum hardness the optimal input values, extrusion ratio of 1.4, die included angle of 20°, ram speed of 3 mm/min and %SiC of 0.4%.

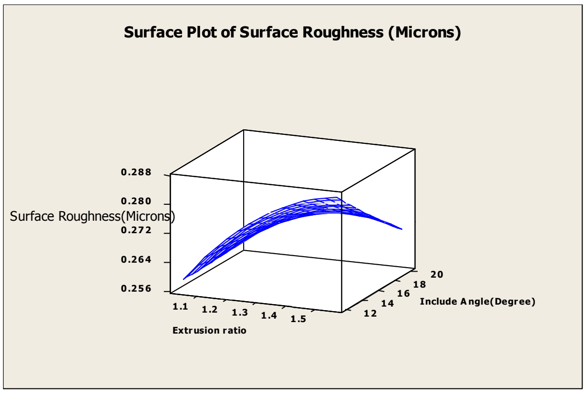

Figure 15a: Surface Plot For Surface Finish (Extrusion Ratio Vs Included Angle)

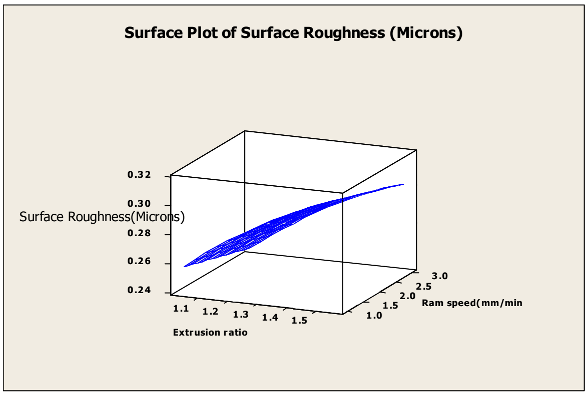

Figure 15b: Surface Plot For Surface Finish (Extrusion Ratio Vs Ram Speed)

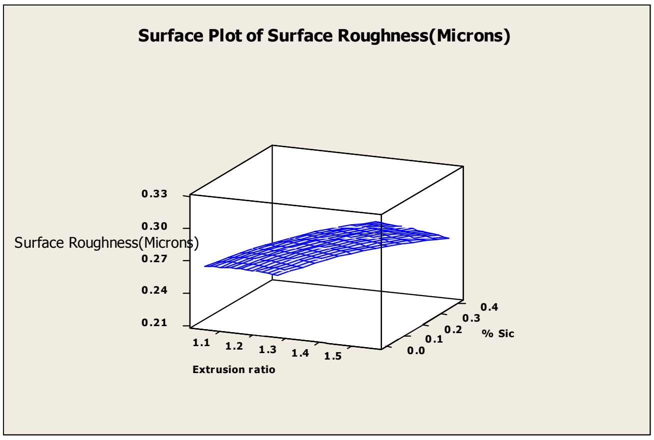

Figure 15c: Surface Plot for Surface Finish (Extrusion Ratio Vs %SiC)

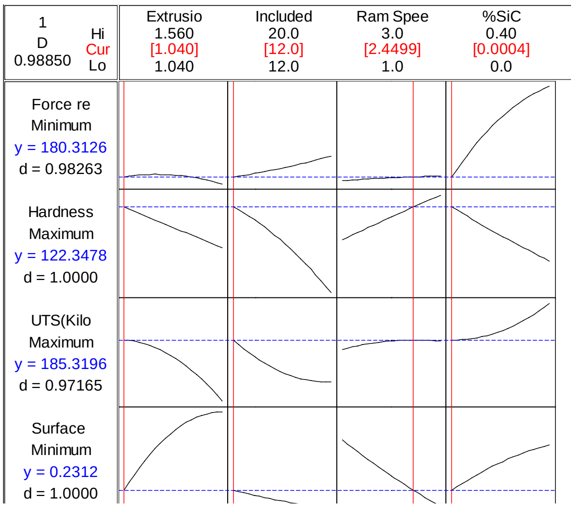

Figure 16: Response Surface Optimizer Table

From Figure-16, it is understood that the optimal input parameters combination of Extrusion ration 1.040, Included angle 12°, Ram speed 2.4499 mm/minute, %SiC 0.0004% the output responses obtained are Force required 180.3126 N, Hardness 122.3478 , UTS 185.3196 MPa and surface finish of 0.2312 microns.

CONCLUSIONS

The following conclusions are drawn based on experiments performed.

- AA6061 nanocomposites are fabricated with ultrasonic assisted cavitation by reinforcing various weight percentages (0.1wt%, 0.2wt%,0.3wt%,0.4wt%,0.5wt%) of SiC nano particles.
- The specimens are extruded at different combinations of input parameters namely extrusion ratio, die angle, ram speed and %SiC. Output responses like Extrusion force required, hardness, tensile strength and surface finish are computed.
- Design of Experiments is adopted and Response Surface Method is used in designing the experiments. 31 experiments are performed using Central Composite Design (CCD).

- Empirical Equations are developed for the output responses by considering second order polynomial equation at 95% confidence level.
- ANOVA analysis was carried out and Fishers test was performed.
- Main plots are drawn for each output response, it is understood that
- Extrusion Force and billet hardness increases with increase in extrusion ratio, die angle, ram speed and % SiC.
- Tensile strength increases with extrusion ratio, ram speed and % SiC. Whereas it decreases with Die Included Angle., this is due to ductile nature of the workpiece.
- Surface roughness increase with increase in extrusion ration and % SiC. Whereas it decrease with increase in Ram speed and included angle due to low stress and smaller contact area.
- Contour plots are drawn to identify the most influencing input parameter on output response. For extrusion force, Hardness, Tensile strength and surface roughness, extrusion ratio is the most dominating input parameter, followed by ram speed,%SiC and included angle.
- Surface plots are drawn to identify the optimalvalues and the following observations are made:
- From Figure's. 12a to 12c, it is clear that for minimum extrusion force the optimal input values, extrusion ratio of 1.1, die included angle of 12°, ram speed of 1 mm/min and %SiC of 0.4 %.
- From Figures. 13a to 13c, it is clear that for maximum hardness the optimal input values, extrusion ratio of 1.4, die included angle of 20°, ram speed of 3 mm/min and %SiC of 0.4%.
- From Figures. 14a to 14c, it is clear that for maximum hardness the optimal input values, extrusion ratio of 1.4, die included angle of 20°, ram speed of 3 mm/min and %SiC of 0.4%.
- From Figures. 15a to 15c, it is clear that for maximum hardness the optimal input values, extrusion ratio of 1.4, die included angle of 20°, ram speed of 3 mm/min and %SiC of 0.4%.
- From response optimizer, it is understood that optimal input parameters combination of Extrusion ratio 1.040, Included angle 12°, Ram speed 2.4499mm/minute, %SiC 0.0004% the output responses obtained are Extrusion force 180.3126KN, Hardness 122.3478, UTS 185.3196 MPa and surface roughness of 0.2312 microns.

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